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Study on Settlement Time Property and Optimization Design of Composite Foundation

Long JIANG [+]

China Institute of Water Resources and Hydropower Research, Beijing 100038 China

Abstract: In order to provide the basis for design and construction of CFG pile, as well as to promote the foundation treatment, settlement time property of composite foundation is studied by means of 3-D liquid-solid coupling numerical simulation methods considering Biot consolidation theory. The results prove that: ① 3-D numerical simulation considering Biot consolidation theory can well study settlement time property of composite foundation; ② Increasing pile length and pile diameter and reducing pile space and compressibility of soil, is helpful for controlling the settlement deformation and the effect of increasing pile length is most remarkable; Increasing pile length, pile diameter and permeability of soil and reducing cushion thickness, pile space and compressibility of soil, is advantageous to shortening the consolidation time and the effect of increasing permeability of soil is most remarkable. ③ The main factors which influence settlement control of pile-slab composite foundation are pile length and preloading, and the optimization design scheme of controlling settlement of pile-slab composite foundation has been carried out in the paper. The scheme is simple and practical, and can be used as scientific basis for the optimization design, and can guide design and construction of high speed railway.

Keywords: Pile-slab composite foundation; Settlement time property; Optimization design;

1 INTRODUCTIONS

CFG pile composite foundation technology is used in course of ground treatment of the Beijing-Tianjin inter-city lines, Wuhan-Guangzhou passenger line and the Beijing-Shanghai High Speed Railway, and can better improve ground bearing capacity, and reduce distortion and save construction costs. Post-construction settlement of the high-speed railway subgrade requirements for 15mm [1], which is much higher than the original roadbed design standards. At this stage, simulation of composite foundation, especially pile-slab composite foundation, is mainly simplified to two-dimensional plane strain problem [2][3], while elastic-plastic theory is mainly used in analysis of settlement property by 3-D model [4][5], considering consolidation theory less. Further, because of the complexity of CFG pile-slab composite foundation, many parameters affect the settlement calculation, and the theory is not mature and far behind the needs of engineering practice.

2 MODELING AND VALIDATION

2.1 Modeling

3-D liquid-solid coupled numerical models of Biot consolidation theory have been established. Elements with eight-node hexahedron reduced integral elements, soil and cushion with C3D8RP, others such as raft, pile and fillings with C3D8R. The model has a total of 25518 elements and 47584 nodes. Meshing diagram is as shown in Figure 1.

2.2 Constitution and Calculation

Constitution model of soil is by elastic-plastic model of 3-D Biot consolidation theory and structures (piles, concrete board, etc.) by linear elastic model. Specific parameters are as shown in Table 1.

[+] Corresponding author. Tel.: +86-10-68786445; fax: +86-10-86515433.
E-mail address: jiangl_zhj@126.com.

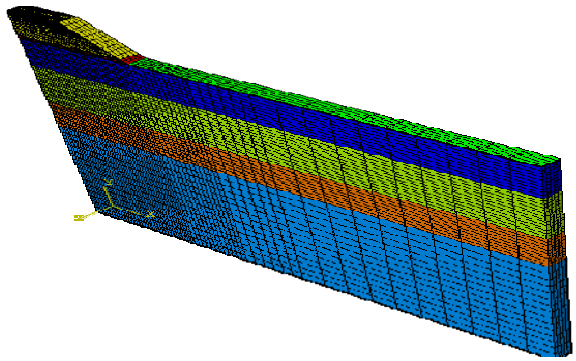


Fig.1 3-D FEM

Table.1 Division and parameters of soil

name	Unit weight	Water content	Void ratio	Cohesion	friction angle	Poisson's ratio	Modulus elasticity	permeability	Friction coefficient
	kg/m^3	%		kPa	°		MPa	$*10^{-6}$mm/s	
1	1910	26.42	0.85	43.6	23.5	0.31	18.4	0.95	0.28
2	2010	23.69	0.69	78.1	27.1	0.26	28.8	0.86	0.34
3	2100	/	/	/	/	0.26	150	/	/
4	2310	/	/	/	/	0.13	500	/	/

2.3 Model Validation

Based on the basic conditions and the physical and mechanical parameters of stratum and structures, model calculation has been carried out. The final settlement curves of the model surface are as shown in Figure 2, and the surface settlement curves at the embankment center in numerical simulation and field monitoring with time as shown in Figure 3.

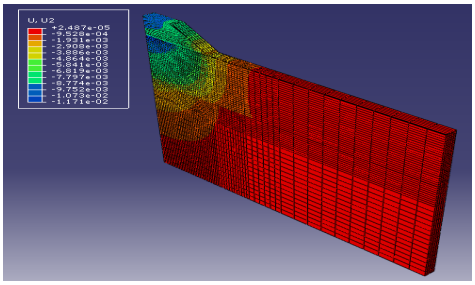


Fig.2 The overall deformation contour of model

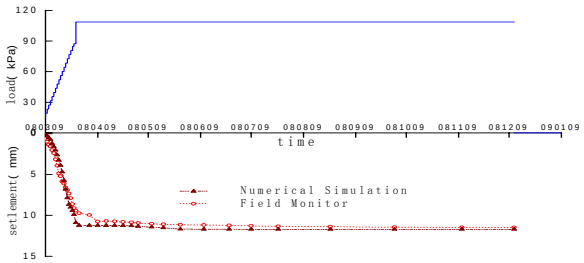


Fig.3 Settlement curves at embankment center with time

From Figure 3 we can see that the maximum surface settlement at the embankment center in numerical simulation is 11.71mm and the settlement in field monitoring reaches a stable value of 11.48mm. The difference of 0.23mm and the maximum error is about 2%. The results show that 3-D numerical simulation considering Biot consolidation theory can well simulate the settlement deformation of field basic working conditions, which is feasible in studying settlement deformation time property.

3 CALCULATION RESULTS AND ANALYSIS

The paper mainly studies the effect of parameters of soil and pile on settlement time property. In view of two layers of soft clay, the second layer is extended down to the model underside. Figure 4 are respectively subgrade surface settlement curves of different thickness of cushion, pile length, pile diameter, pile space, elastic modulus, coefficient of permeability and filling height at the embankment center with time.

Figure 4 show that corresponding subgrade surface settlement decreases by respectively 0.61, 0.63, 0.40 and 0.23mm for each additional 0.1m of cushion thickness from 0.2m; and the settlement decreases by respectively 3.93, 4.33, 4.52 and 4.98mm for each additional 2m of pile length from 8m; and the settlement increases by respectively 0.48, 0.57, 0.73 and 0.91mm for each additional 0.2m of pile space from 1.6m; and the settlement decreases by respectively 26.74, 24.75, 21.91 and 18.5mm for each additional 10MPa from 10MPa. As for field working conditions, soil-related elastic modules and coefficient of permeability take fixed value, and thickness of cushion usually takes 0.4m around better, and pile diameter usually takes 0.4m and 0.5m and also fixed value.The results show that contribution rate of effect of pile space on settlement

control is 0.08, while the rate of pile length is 0.92. So, pile space can be a fixed value in controlling settlement process.

The above analysis shows that the main factors which influence settlement control of pile-slab composite foundation are pile length and preloading.

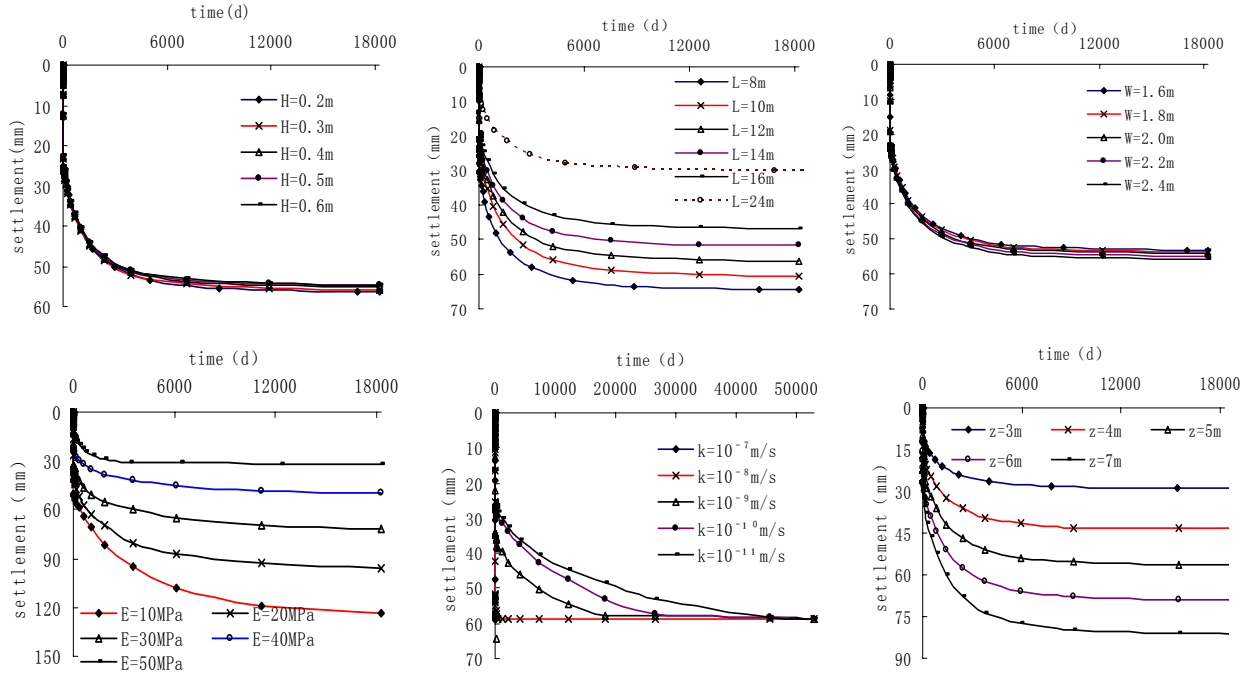
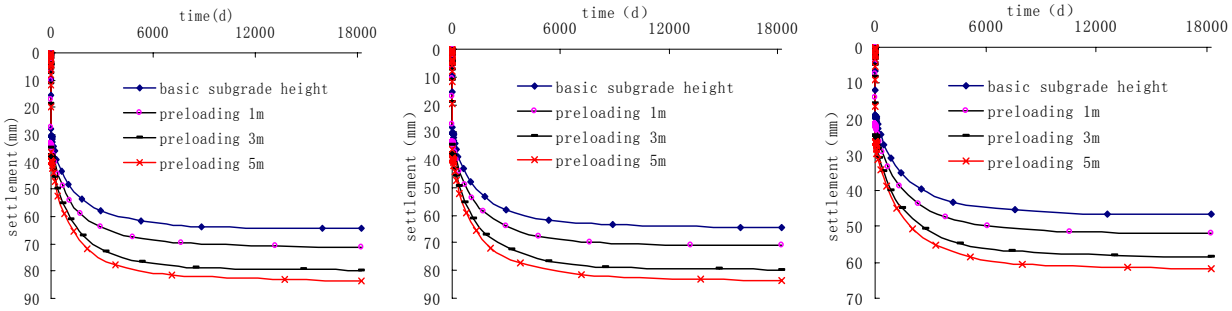


Fig.4 Settlement curves with time

4 OPTIMIZATION DESIGN BY CONTROLLING SETTLEMENT

Figure 5 is settlement curves of different preloading and pile length of 8m with time; Figure 12 is the curves of pile length of 12m; and Figure 13 is the curves of pile length of 16m.



(a) L=8m (b) L=12m (c) L=16m

Fig.5 Settlement curves with time

From Figure 4 and 5 we can see that changing of pile length and preloading height can better control the early occurrence of settlement and uploading time, to meat the requirements settlement and the construction period. Processing optimization data and drawing 3-D settlement curves of different pile length and different preloading with time is as shown in Figure 6. The optimization scheme by controlling settlement and construction period is as shown in Figure 7.

Figure 7 shows that no options can be selected by construction period of 90 days and controlling settlement of 10mm; the better scheme is pile length of 16m and preloading of 3m by construction period of 90 days and controlling settlement of 15mm; the optional scheme is pile length of 12m and preloading of 1m or pile length of 8m and preloading of 5m by construction period of 270 days and controlling settlement of 15mm, and then the optimal solution can be found by comparing their economic; the better scheme is pile length of 12m and preloading of 3m by construction period of 540 days and controlling settlement of 5mm. By analogy the main assessment factors are control settlement amount and construction period. The optimization is simple and practical, and can be used as scientific basis for the optimization design, and can guide design and construction.

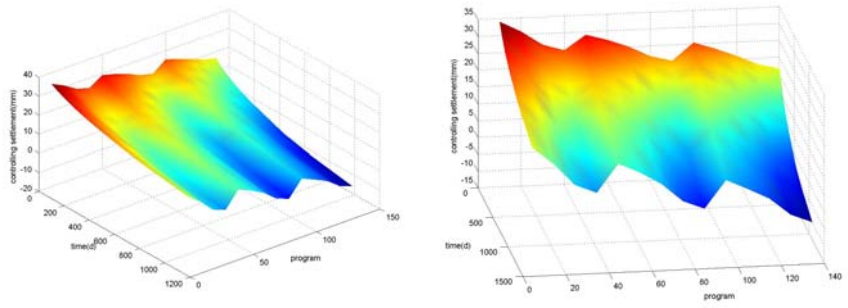


Fig.6 Control settlement 3-D curves of different schemes with time(L=12m)

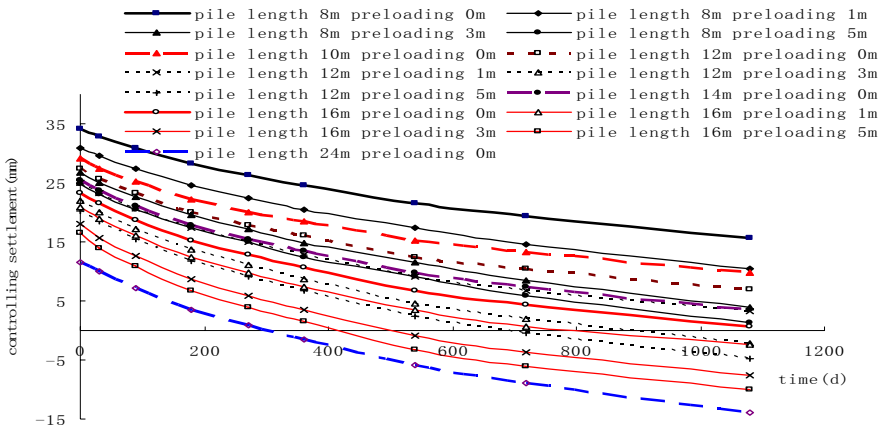


Fig.7 The optional schemes by control settlement and construction period

5 CONCLUSIONS

(1) By comparing and analyzing finite element model based on field monitoring data, it is verified that 3-D liquid-solid coupling numerical simulation considering Biot consolidation theory can well simulate the settlement deformation of field basic working conditions, which is feasible in studying settlement deformation time property.

(2) Increasing pile length and pile diameter and reducing pile space and compressibility of soil, is helpful for controlling the settlement deformation and the effect of increasing pile length is most remarkable; Increasing pile length, pile diameter and permeability of soil and reducing cushion thickness, pile space and compressibility of soil, is advantageous to shortening the consolidation time and the effect of increasing permeability of soil is most remarkable.

(3)The main factors which influence settlement control of pile-slab composite foundation are pile length and preloading, and the optimization design scheme of controlling settlement has been carried out in the paper.

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